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ENTROPY: A CONCEPTUAL APPROACH TO MEASURING SITUATION-LEVEL WORKLOAD WITHIN EMERGENCY CARE AND ITS RELATIONSHIP TO EMERGENCY DEPARTMENT CROWDING

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☐ Abstract—Background: Emergency department (ED) crowding correlates with patient safety. Difficulties quantifying crowding and providing solutions were highlighted in the recent Institute of Medicine (IOM) report calling for the application of advanced industrial engineering (IE) research techniques to evaluate ED crowding. ED personnel workload is a related concept, with potential reciprocal effects between the two. Collaboration between emergency medicine and IE is needed to address crowding and ED personnel workload. Objective: We review ED crowding and workload literature, relationships between workload and ED crowding, and the potential application of information theory as implemented in IE frameworks entitled "entropy" in evaluating both topics. Discussion: IE techniques have applications for emergency medicine and have been successful in helping improve ED operations. Lean and Six Sigma applications are some of these techniques. Existing ED workload measures don't account for all aspects of work in the ED (acuity, efficiency, tasks, etc.) Crowding scales, such as NEDOCS (National ED Overcrowding Study) and EDWIN (ED Work Index), fail to predict ED crowding. A new measurement "entropy" may provide a more comprehensive evaluation of ED workload and may predict work overload seen with crowding. Entropy measures task-based work and the information flow involved. By assigning an entropy value to patient type-specific tasks, we might predict when the ED is overwhelmed, and crowded. Conclusions: IE techniques provide solutions to the ED crowding problem and improve ED workload. We propose a technique novel to medicine: "Entropy," derived from information theory, which may provide insight into ED personnel workload, its potential for measuring ED crowding, and possibly, in predicting an overwhelming situation. © 2014 Elsevier Inc.

☐ Keywords—workload; crowding; operations; boarding; process improvement

INTRODUCTION

In 2006, the Institute of Medicine (IOM) released its report entitled "Hospital-Based Emergency Care: At the Breaking Point" (1). It appropriately characterized crowded emergency department (ED) conditions as a pervasive problem facing much of the United States. Additionally, ED crowding is also a problem worldwide, and a large body of additional work has further shown the detrimental effects of ED crowding (2–6). In its 2008 report entitled "Emergency Department Crowding: High-Impact Solutions," the American College of Emergency Physicians task force documented the detrimental effects of crowding, such as increased medical errors, increased mortality rates, increased time to treat those with critical illnesses, and increased total length of stay

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(3,6–10). Still other work has suggested that ED workload and factors associated with crowded conditions may contribute to medical malpractice claims (11). Finally, ED workload, particularly that for ED nurses, is related to the care they provide to both inpatient boarders and newly arriving ED patients, which implies a direct relationship between ED workload and ED crowding (12). Given these concerns, ED crowding and the interrelated concept of workload and the reciprocal effects of these entities are an ongoing problem that we must continue to study, address, and strive to remedy.

The IOM report described many negative effects of crowding, including lack of system integration, nonavailability of specialty care, specialty shortages, and lack of emergency preparedness. The primary cause of crowding, according to the Government Accountability Office, is the practice of boarding inpatients in the ED while they await an available bed (13). Boarding may last from a few hours to days, decreasing the workspace available to see emergency patients, but more importantly, increasing the workload of the ED nurses, providers, and other ED personnel.

Most industries, including health care, can improve their day-to-day workflow and operations such that they are more productive, more efficient, and more cost effective (14,15). Clearly, one of the most obvious solutions to ED crowding would be to move admitted patients elsewhere throughout the hospital, however, that process has been adopted by only a few hospitals (15,16). Given the systemic hurdles that many EDs face regarding boarding, combining ED process improvement initiatives *in conjunction with* efforts to improve hospital-wide systems can reduce crowding.

Over the past two decades, research and business practice improvements have focused on increasing efficiency and streamlining all aspects of service and industrial models. Much of this work has been conducted by industrial engineering researchers utilizing advanced quantitative techniques such as Six Sigma, Lean thinking, and computer modeling and simulation. One goal proposed by the 2006 IOM report is the application of these industry-proven and successful methods to the health care industry to better understand overcrowding and its effects (1). Translating these advanced industrial engineering research techniques into the health care system will not only help us to better understand work flow inefficiencies within EDs, but also throughout operations hospital wide. The purpose of this article is to propose the use of a proven information theory known as "entropy" as a new means to measure workload in the ED and potentially provide an early warning of work overload in busy or crowded EDs. Such a model may be used to select tasks to offload and changes to improve efficiency as well as to better quantify and understand ED workload as a whole. We also propose that ED workload and crowding are related entities, and entropy may serve as a proxy measure for predicting overwhelming and crowded conditions.

DISCUSSION

Lean and Six Sigma

A number of industrial engineering research-based techniques have been successfully translated into the health care environment, and particularly emergency medicine. These include but are not limited to "Six Sigma" and "Lean" thinking (17–19). Six Sigma is a technique pioneered in the early 1980s by Motorola Corporation (Libertyville, IL), and utilizes a data-driven approach to reduce the amount of error and rework that occurs in a manufacturing process (20,21). Six Sigma requires a cataloging of tasks and measurement of the mean, median, and standard deviation of those tasks. The goal is to reduce variability and error, but in part, the effectiveness of Six Sigma relies on the stability of the system itself. "Lean" was developed by Toyota (Toyota, Japan) in the early 1990s and focuses on reducing waste within any system of operations by improving those processes that create "value-added" to the product and customer, removing any processes or procedures that do not add value, and are thus seen as wasteful (22). Both techniques were developed for improvement of manufacturing industries, but both have also been successfully translated into the service industry and specifically, into health care. Areas of positive impact have been improvement of operating room throughput, and improved door-to-balloon time (17,19). Specifically within emergency care, process improvement techniques such as "Lean" thinking have been successfully employed in improving a variety of processes, including the reduction of wait times and in the development of rapid triage and treatment protocols (23,24).

The successful application of these types of industrial engineering (IE) tools have led to their acceptance as types of process improvement techniques within health care, with roles that seem to be best utilized when tailored to a given need. Given their success, other potential applications of IE may be translated into emergency care. However, instability of the ED environment challenges the successful application of these process improvement techniques, yet there are some examples where applications have been useful. Other theories and techniques applied within IE frameworks, such as entropy as described below, may provide additional methods to

evaluate ED workload within the complex setting of emergency care.

Measurement of Workload

ED crowding has impacted nursing and ED provider workload, quality of care, and patient safety. Asplin et al.'s initial conceptual model of ED crowding, the input-throughput-output model, identified several factors that contribute to ED crowding (25). Although their model deals primarily with length of stay and quantity of patients, averaged over time there is a rough correlation between high patient volume and an increase in emergency workload. Furthermore, there is a possibility that as ED workload increases, ED throughput may decrease given a multiplicity of demands on existing resources and personnel. Increased amounts of patient input from different sources increases the demand for ED care. This increased input is from a variety of different sources but falls into three general categories: emergency care, unscheduled urgent care, and safety net care (25). ED throughput outlines the path of care through ED processes and is subject to methods to improve the efficiency of these processes. However, as with all processes that rely on human capital, their efficiency may be subject to the quality, numbers, and fatigue factors of the participants. Finally, there is reduced ED output, which has been largely defined by the boarding of admitted inpatients in the ED (5,13,25). Implicit in this discussion of the model of ED crowding is that *crowding itself has the propensity to increase the workload on ED personnel*. Korn and Mansfield reported that the dichotomy of providing care to both inpatient boarders and newly arriving ED patients absorbs the work performed by ED staff, which logically requires an increasing workload as volume rises, to maintain the same level of care (12). The high workload of ED personnel leads to several important consequences. Research shows that a heavy nursing workload adversely affects patient safety (26). Furthermore, it negatively affects nursing job satisfaction and contributes to high turnover and the nursing shortage (26). Stress from uncertainty has been highly correlated with professional burnout, and it has been shown that physicians who felt their job demands were too high had significantly lower job satisfaction and higher rates of burnout (27,28). Considering the relationship between crowding and the workload of ED personnel, Figure 1 illustrates the potential causal relationship by incorporating a feedback control loop, which is the supply of ED care and effective resources. As ED input (either intrinsic from crowding, or extrinsic) increases, crowding levels continue to increase, as does the demand for ED resources, both physical and cognitive. As a result, the workload of ED personnel increases and the ability of ED resources to increase ED output decreases from reduced efficiency and fatigue factors as the multiple variant demands are presented to the limits of human interaction. All factors such as intrinsic/extrinsic inputs, resources, demand, and resource workload converge on a theoretical point, which creates a feedback loop with crowding at the center.

The conflict between the increased demand and stable or even decreased effective supply of ED personnel has the potential to form a self-perpetuating cycle and worsen the circumstances that govern and surround ED crowding and correspondingly increase ED personnel workload. Increased ED personnel workload increases the likelihood of developing the negative consequences outlined earlier. Therefore, it is very important for decision-makers and researchers alike to obtain a systematic and comprehensive assessment of ED workload in variable conditions such that measures can be taken to mitigate both crowding and increasing personnel workload.

A variety of approaches to the measurement of nursing workload have been developed, and although substantial differences exist among the approaches, at minimum they all aim to estimate the total hours of nursing staff required to care for patients (12,29). Various measures have been devised to quantify the nursing workload and can be categorized into four levels: 1) unit level, 2) job level, 3) patient level, and 4) situation level (30).

Unit-level workload is calculated by the summation of nursing tasks performed by a group of nurses during a specific shift. Patient-to-nurse ratio (Pt.: N) is the most commonly used measure at this level. Previous studies provide strong evidence that a large Pt.: N ratio can lead to negative outcomes on patient care, such as increased morbidity and mortality (26,31,32). Existing literature indicates that in the ED, Pt.: N ratios are often very high (33). The combination of emergency nursing shortages and increasing ED patient volume has the potential to increase ED Pt.: N ratios even further; however, the use of a simple metric like Pt.: N ratio does not adequately measure waiting-room patients, the effect of long waits for care, or the change in workflow and workload required to care for both inpatient boarders and new ED patients. Furthermore, this ratio fails to capture the complexity and flow of the tasks performed by ED personnel, and does not adequately describe the details of the cognitive and physical factors that may largely contribute to job satisfaction, patient safety, avoidance of errors, and the impact of these on patient care.

Job level workload measures the variability between two types of workers performing similar tasks under similar conditions, such as ED nurses and ED providers, or ED personnel vs. similar personnel in other specialties/units. This type of research has been used to investigate

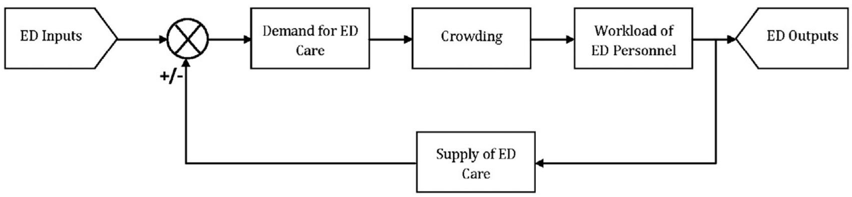

Figure 1. Relationship between emergency department (ED) crowding and ED personnel workload.

the impact of workload on burnout and performance (34). However, this process does not account for the difference in experience between workers.

At the patient level, acuity may be a major contributor to workload. Solberg et al. attempted to account for this by multiplying the number of patients treated by the acuity level of the patient (35). However, this model has not been robust, and recent studies show that factors other than patient acuity significantly affect nurse workload at the patient level (36).

In similar fashion to the work done in nursing research, there has been a variety of work done on evaluating physician workload, but much of this work has focused on patient:physician ratios and hours spent on patient care (37,38). Within emergency care, in addition to workload reported as service times, much information on productivity is available, such as relative value units (RVUs), RVU/h, and patients seen per hour, but far less is available on systematic evaluations of emergency physician workload, particularly at the task level (39). 1n 2011, Chisholm et al. evaluated emergency physician tasks as they were related to interruptions (40). Earlier, Levin et al. looked at task-related workload but pointed out that simple statistics such as mean and median were a poor representation of workload in this setting (41). They further report that calculations such as workload density were unable to characterize workload changes over time. In this work, they also discussed the potential difficulties with utilizing several additional more standardized workload analysis tools and they called for more research in this area. There is no literature that systematically evaluates task-based workload and the potential for effects and reciprocal effects of ED crowding on this workload.

Entropy

Entropy may be employed as a remedy to the shortcomings of the above levels of measure. Using this framework, nursing and provider workload is quantified initially by evaluating the frequency and duration of tasks and workload that is perceived by ED personnel. Unlike other measures of workload that rely primarily on patient-to-nurse (or -provider) ratio and patient acuity, entropy attempts to measure the workload as *experienced* by a nurse or provider at the microsystem and task level. Subsequently, using direct observation combined with personnel and worker surveys, the time, physical effort, and cognitive burden of each task is calculated and converted (see Appendix 1) to an entropy value (42–44). Task-level entropy values can also be combined to create an aggregate entropy measurement for physical and cognitive tasks as well as over time. This permits the analysis of work at a micro/patient level. At this level, many contextual factors in the working environment are captured, such as poor facility design, ineffective communications among team members, frequent task switching, computerized order entry and charting, and ergonomics. The impact can be evaluated and reassessed in changing environments (crowded vs. noncrowded). ED nursing and provider workload is a complex and multidimensional construct that requires an equivalent multidimensional measure to evaluate, thus, the concept of situation-level workload and entropy may be an appropriate tool to implement.

An example may help to clarify the usefulness of entropy. Consider two nurses each caring for 4 patients. The first nurse has 3 boarded patients admitted for possible acute coronary syndrome who are awaiting placement in a chest pain unit. All are young, otherwise healthy, and largely care for themselves. The fourth patient has a fractured arm and is waiting to go to the operating room. The second nurse has 3 patients with vomiting, diarrhea, and abdominal pain. All are acutely symptomatic. The fourth patient is in alcohol withdrawal, in restraints, and is on Clinical Institute Withdrawal Assessment protocol. Standard measurements of Pt.: N ratio would suggest these two nurses have equal workloads. Existing measures utilizing acuity would suggest that nurse 1 may have a higher workload accounting for possible cardiac causes. However, entropy measures would indicate, and likely more correctly, correlate with the nurses' self-assessments, that nurse 2 has the higher workload. Numerically (see Appendix 1 for equations, and Table 1 for summary), using estimates of the frequency and duration of the nurses' task load based on initial observational data, we would see that the entropy calculations for nurse 2 would clearly indicate a workload roughly twice that of nurse 1.

Table 1. Estimated Nursing Tasks and Entropy Calculations

	Nurse 1	Nurse 2	Ratio (Nurse 2/ Nurse 1)
Number of patients	4	4	1
Patient acuity level	3	3	1
Total time spent on tasks	255.2	562.3	2.20
Entropy (10-h shift)	1.89	3.75	1.98

Additionally, although we might consider that a simple linear total time calculation could provide a reasonable estimate of workload, it is unlikely that simple time calculations would capture the complexity of the nurse's true workload. In some cases, nurses might be able to perform a number of tasks simultaneously, such as observing the alcohol withdrawal patient from the door to be sure they are not a danger to themselves, but will also be able to answer telephone calls, computer document, and discuss issues with families. If this were the case, total time calculations would clearly overestimate the workload, whereas an entropy calculation would more realistically capture the information flow and actual complexity of the tasks at hand. We might also consider another circumstance where a linear total time calculation would indicate roughly twice the time spent on the tasks, but due to the immediate nature of the task mix (giving meds, intravenous fluids, patient hygiene) in which a variety of the tasks could not be postponed, a nurse might need to request additional patient care resources. Here, multiple nurses, or a combination of nurses and patient care technicians would be required to complete the total workload of the single nurse in a timely fashion. Additionally, it is likely that the degree of illness that nurse 2's patients are experiencing and the types of illnesses present are likely to require the time-consuming process of obtaining substantial supplies and materials, often at multiple unexpected and random points. Further, there is a much larger degree of randomness by which each patient's symptoms are likely to manifest for nurse 2. This will require far more frequent task switching, obtaining of materials, task interruptions, requests for assistance, order clarification, and random points of direct patient contact for nurse 2 than nurse 1. The total time calculation would be the same for the patient and task load, but the resource utilization would clearly be heavier for nurse 2. Standard total time measurements would not truly capture the relationship and interplay between resource utilization and physical and cognitive workload. Yes, in some cases, total time measurements might be equivalent, but in many cases would fall significantly short of a full description. Utilizing entropy as a measurement would capture the true relationships far more completely and be far more useful in resource and patient allocation. Clearly, a better understanding of this phenomenon would be beneficial to both health care workers and patients, in directing additional resources toward the nurse(s) who are actually experiencing the greater work overload.

Although applicable over a broad range of similar care environments, entropy is also site-parameter specific. For example, in an academic medical center with an on-site cardiac response team, the emergency physician workload for a patient with an ST-elevation myocardial infarction is significantly less than in a community hospital where the patient received thrombolytics and was then transferred to a larger center with percutaneous transluminal coronary angioplasty capability.

Entropy has been employed in the study and evaluation of supply chain models within the manufacturing industry (45). It is derived from Shannon's information theory that quantifies uncertainty in any system by quantifying the information flow into and out of the system (46). At its most basic level, Shannon proposed that the flow of information in any system can be thought of as a series of discrete packets of information that have a certain probability of existing (46). These packets are of a certain degree of complexity, depending on the initial construct of the information transmitted and the system they represent. Degrees of complexity of the entire system can increase as a result of a variety of influences on the system. Particularly influential in increasing the complexity of information flow is the probability of any single packet of information existing, particularly if that probability of existence is dependent on the preceding or surrounding information and the relationship of probability distributions between interrelated factors. A model or process that produces such packets of information, which are governed by probability distributions, is known as a stochastic process (46).

There are a complex series of mathematical equations outlined in Appendix 1 that discuss the methodology of determining information flow, or entropy, in relation to the probabilities within the system utilizing Shannon's basic theory. However, it is easy to comprehend the basic concept of utilizing this model within emergency medicine to better understand the complex nature of ED workload in which tasks are often directly related to the preceding tasks and surrounding environment.

Entropy has been proposed as a method for quantifying workload within the ED, particularly during times of surge (47). Within health care, providers must perform a complex and interrelated series of physical and cognitive processes that culminate in the care the patient actually receives. Not all of the tasks that are performed possess the same intricacies, but something as seemingly routine as a nurse placing an intravenous line in a patient requires a significant amount of preplanning, assessment,

materials assembly, manual dexterity, and motion. Using baseline measurements, entropy can potentially draw from information gathered by newer electronic track board and order-entry systems, and when combined with order and nursing documentation completion, is likely to be able to calculate the workload in near real time. Entropy measures the complexity of individual tasks involved in the work–both cognitive and physical–and then relates these to the frequency of the task as well as the subjective workload of the task. The greater the entropy within a system, the more complex the system is, as well as being less efficient and potentially, more unsafe. Information theory and the entropic approach seek to quantify the information contained in the physical and cognitive components of a complex series of tasks that occur in the ED environment and translate these components into a measurable index that captures the true ED personnel workload.

Entropy, if applied to emergency care, may help us understand how the workload changes during times of ED crowding and to identify those tasks that may be offloaded to other personnel to create a safer environment. Furthermore, it may assist us in determining which tasks, or series of tasks, can be made more efficient, less complicated, and safer to perform.

Several additional considerations are appropriate to point out regarding entropy, although they are past the scope of this article. First, the use of electronic tracking systems and order entry will potentially allow workload data to be calculated in near-real time. Group or even individual workload can be calculated and additional resources allocated before unsafe conditions occur. Secondly, advanced computer simulation (within the realm of this group's capability, but outside the scope of this article) may be combined with the entropy model to project the success or failure of potential changes in existing workflows to reduce total, group, and individual workload *prior to* introduction to the clinical environment.

Finally, we propose that entropy can serve as a unifying metric that could be used to predict crowded conditions, as well as to indicate where improvements might be made in workflow. Existing crowding scales such as NEDOCS (National ED Overcrowding Study) and ED-WIN (ED Work Index) have used nursing and provider perceptions of crowding as the gold standard under which they have been validated (48,49). They have been criticized for their inability to identify crowding conditions before they occur such that resources may be mobilized to intervene prior to an unsafe and crowded environment (50). Some have commented that crowding is easy to recognize, but often difficult to define, and often a unique perception based on individual ED and personnel conditions as much as on volume-related metrics (48). It is reasonable to consider that a particular nurse or provider's perception of how crowded their environment is may be *directly related* to their workload and the degree of complexity that surrounds the tasks they perform. Increasing task-level workload, increasing information flow, and increasing complexity may be an early proxy indicator of when the environment is beginning to feel crowded to its participants. Thus, calculated entropy may be a way to capture an environment undergoing transformation to a crowded condition before it actually occurs.

In considering entropy as a proxy measure of crowding, we propose that workload and system complexity are abstract concepts that are quantifiable by utilizing entropy, but are also a complex combination of difficult-to-measure variables such as environment type, workplace size, differing simultaneous objectives, and uncertainty (47). Although each of these variables (and others) can be independently isolated and quantified, it is the relationship and interaction between these variables that creates the complexity of any system, and thus the entropy contained within it. What has eluded researchers for some time has been the idea of a universal measure of ED crowding. This is because the condition of crowding itself, although relative to actual patient volume, is largely an abstract circumstance similar and directly related to the multidimensional constructs of workload and system complexity (48). Crowding is *felt* by ED personnel in response to the relationship and interaction among a variety of characteristics, many of which may be individual and unique to each particular ED. We propose that as a result of this complex interrelated series of characteristics, system complexity and ED crowding are tightly correlated, and that entropy may measure the "feel" of crowding associated with system complexity and increasing information flow and may be used to predict potential crowding conditions. We propose that in similar fashion to calculating ED workload, automated calculations incorporated into electronic health record systems are likely to be able to be modified and applied for real-time calculation of system complexity and ED crowding. However, much more work needs to be conducted with respect to this concept.

Prior Work

Entropy has been previously successfully used to examine the workload of telemetry nurses in a busy urban hospital (Lin 6/2010) (51). Interviews and focus groups of these nurses were conducted to develop a list of tasks they performed. These were verified by direct observation, and the time on task, as well as its frequency, was recorded by an observer. The nurses were then asked to rate the physical and cognitive workload that they experienced for

each task utilizing a five-point Likert scale. They also verified the duration and frequency of each task. Data derived from the interviews, questionnaires, and direct observations were then used to calculate physical workload (subjective difficulty *duration*frequency) and cognitive work (subjective difficulty*duration*frequency) for each task. Using complex formulas listed in Appendix 1, a value of the entropy for that worker or the work group as a whole can be calculated. In total, the direct observation conducted was able to validate the self-reported data, with a high degree of agreement indicating a good model fit. This preliminary work suggests a higher probability of success as a potential model for ED conditions.

These calculations characterize both cognitive and physical workload, and evaluate the static and dynamic states that exist within the system. The static complexity is essentially the sum of the fixed resources within the system combined with the probability distribution surrounding their usage and position within the system. Dynamic complexity is a measure of the added information required to maintain stability of the system when it deviates from its normal behavior—planned, or unplanned events (47). The data can be gathered under different conditions (crowded vs. noncrowded) and the effect on workload made apparent. By examining the changes in workload and total entropy, targeted improvements can be identified. For example, when entropy is high, certain high workload tasks may be offloaded to less skilled workers. As outlined before, coupling computer simulation with entropy as the modeling concept, the effect of such changes can be calculated prior to implementation.

Although a formidable goal, if evaluation of and reduction in ED system complexity may be achieved by successfully employing information theory and the entropic concepts proposed here, one can envision the possibility that they may be translated hospital wide to reduce the workload and systems complexity that can result in an unsafe and inefficient health care working environment.

CONCLUSION

ED crowding and personnel workload are multidimensional and related entities, and exhibit reciprocal effects on each other. Existing measures of workload fail to capture the complex nature of the work that is performed by ED personnel. Existing measures of ED crowding fail to provide predictive value in determining ED crowding, largely because they do not capture the *feeling* of crowding that ED personnel undergo prior to the actual crowded conditions. Existing measures of ED workload and crowding alike fail to capture the complex relationship between individual variables that affect both workload and crowding. In this work, we have proposed the concept of system complexity, information flow, and entropy as a viable method of evaluating ED personnel workload and possibly ED crowding, and proposing solutions for EDs and other hospital environments. Although much additional work needs to be conducted to fully explore its applications, entropy is likely to be a viable model that may be employed to evaluate and improve ED workload and efficiency, and possibly improve the safety of patients during times of crowding. Expanding this to include additional hospital operations may have the added effect of improving the systems issues that provide the undercurrent for why EDs remain crowded. Finally, entropic results may be a viable metric and measure that could potentially be integrated into existing medical record systems and automated for ease of use to forecast the increasing information flow and system complexity associated with the transformation to a crowded ED condition, and has the potential to resolve some of the issues that surround current ED crowding scales.

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APPENDIX 1

A system's entropy represents the amount of information required to describe the state of the system and render it equivalent to the system complexity (42,43). In a dynamic environment, the operational complexity can be quantitatively defined as the amount of information required to monitor the state of the system to manage it (44). Suppose that there are n symbols $\{a_1, a_2, \ldots, a_n\}$, and the probability that symbol a_i can be observed is p_i.

Assume that the symbols can be observed independently. So, the amount of information obtained from a particular observation of symbol a_i is

$$I(p_i) = \log(1/p_i) \tag{3-1}$$

In the long run, if N observations are obtained, there will be (approximately) $N \times p_i$ occurrences of symbol a_i. Thus, in the N (independent) observations, the total information I is:

$$I = \sum_{i=1}^{n}(N \times p_i) \times \log(1/p_i) \tag{3-2}$$

Then the average information obtained per symbol is

$$I/N = (1/N)\sum_{i=1}^{n}(N \times p_i) \times \log(1/p_i)$$

$$= \sum_{i=1}^{n} p_i \times \log(1/p_i) \tag{3-3}$$

Suppose that we have a set of probabilities (a probability distribution) $P = \{p_1, p_2, \ldots, p_n\}$, so the entropy of the distribution P is defined by:

$$H(P) = \sum_{i=1}^{n} p_i \times \log(1/p_i) \tag{3-4}$$

If the probability distribution $P\ (x)$ is continuous rather than discrete, then the entropy of the distribution is defined by:

$$H(P) = \int P(x) \times \log(1/P(x))dx \tag{3-5}$$

In health care settings, each task performed by providers or nurses can be viewed as a symbol a_i. Suppose there are n tasks $\{task_1, task_2, \ldots, task_n\}$and the time spent on $task_i$ is represented by the set$\{t_1, t_2, \ldots, t_n\}$. Assume the total time period to be evaluated is T (i.e., one hour, one shift, etc.). The time proportions of the tasks form a probability distribution $P = \{p_1, p_2, \ldots, p_n\}$ where $p_i = t_i/\mathrm{T}$. We also assume that the frequency of $task_i$ is f_i during the total evaluated time period. The time spent on each task and the frequency can be obtained from the questionnaires and observations.

The total information obtained from $task_i$ during N observations in the total evaluated time period T can be utilized to estimate the workload of $task_i$ from the equation

$$I(p_i) = f_i \times \log(1/p_i) \tag{3-6}$$

Therefore, the entropy H (p) can estimate the workload of all tasks performed by providers or nurses during the total evaluated time period.